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The Relationship of Litterfall to Basal Area and Climatic Variables in the *Rhizophora mucronata* Lamarck Plantation at Tritih, Central Java, Indonesia

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Abstract

Components of litterfall were measured for one year (January to December 1985) at five sites in the *Rhizophora mucronata* Lamarck plantation at Tritih, in the Rawa Timur forest district, Cilacap. The annual litterfall (t ha^{-1}) was 8.193–8.236 in medium *R. mucronata* stands, 10.395 in a tall *R. mucronata* stand and 7.058–7.369 in small *R. mucronata* stands. Significant correlations were found between annual litterfall of individual *R. mucronata* stands and their respective basal area measured at 30 cm above the highest prop root. The seasonal pattern of litterfall was most closely related to total rainfall ($r=0.913$), mean maximum temperature ($r=0.931$) and minimum temperature ($r=0.932$). However, fall of non-leaf materials was also related to the force of the wind run associated with the last monsoon.

Introduction

The mangrove forests of Segara Anakan Cilacap represent important natural resources for Perum Perhutani (The State Forestry Corporation), but they are being progressively degraded due to illegal cutting and other human interference [Sukardjo 1984].

At present, little is known of litter production and decomposition processes in these forests [see Sukardjo 1989; Sukardjo and Yamada 1992], and this kind of information is needed to develop an understanding of stand dynamics, nutrient cycling and the quantification of fuel resources.

Litterfall in the *R. mucronata* Lamarck plantation was collected for one year (January to December 1985) and sorted into the following components: leaf, fruit, flower, branch and other materials.

This paper considers the influence of stand basal area and seasonal temperature on litterfall of *R. mucronata* stands. Detailed biomass estimates have been published [Sukardjo and Yamada 1992]. This paper constitutes the third part of an ecological study of the *R. mucronata* plantation of Tritih, Cilacap, which was conducted from January 1985 to December 1986, and forms part of a long-term program aimed at a comprehensive understanding of mangrove plantation ecology in this region.

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Study Area

Stands representing five *R. mucronata* types were selected for sampling at the Rawa Timur forest district, near Tritih village (Fig. 1). Representative 50 m×50 m (0.25 ha) plots were established at each of the sites. Following the classification in terms of management of the Perum Perhutani, there were two sites of medium *R. mucronata* stands (site I and IV, Mean Dominant Height=MDH =5.84 m and 6.10 m), one of tall *R. mucronata* stand (site V, MDH=7.10 m) and two sites of small *R. mucronata* stands (site II and III, MDH=5.40 m and 5.20 m). The characteristics of the sites are given in Table 1. Table 2 shows the typical diameter class distribution of *R. mucronata* Lamarck trees in Tritih. The majority of trees (51.02%) belong to the diameter class 4.00-6.00 cm; and all the *R. mucronata* stands in Tritih can be classified as saplings (trees with diameter 2-9.99 cm). Live basal area (m^2 ha^{-1}), live stems per hectare and leaf litter production (t ha^{-1} $year^{-1}$) for sapling estimates for sites I, II, III, IV and V are presented in Table 1.

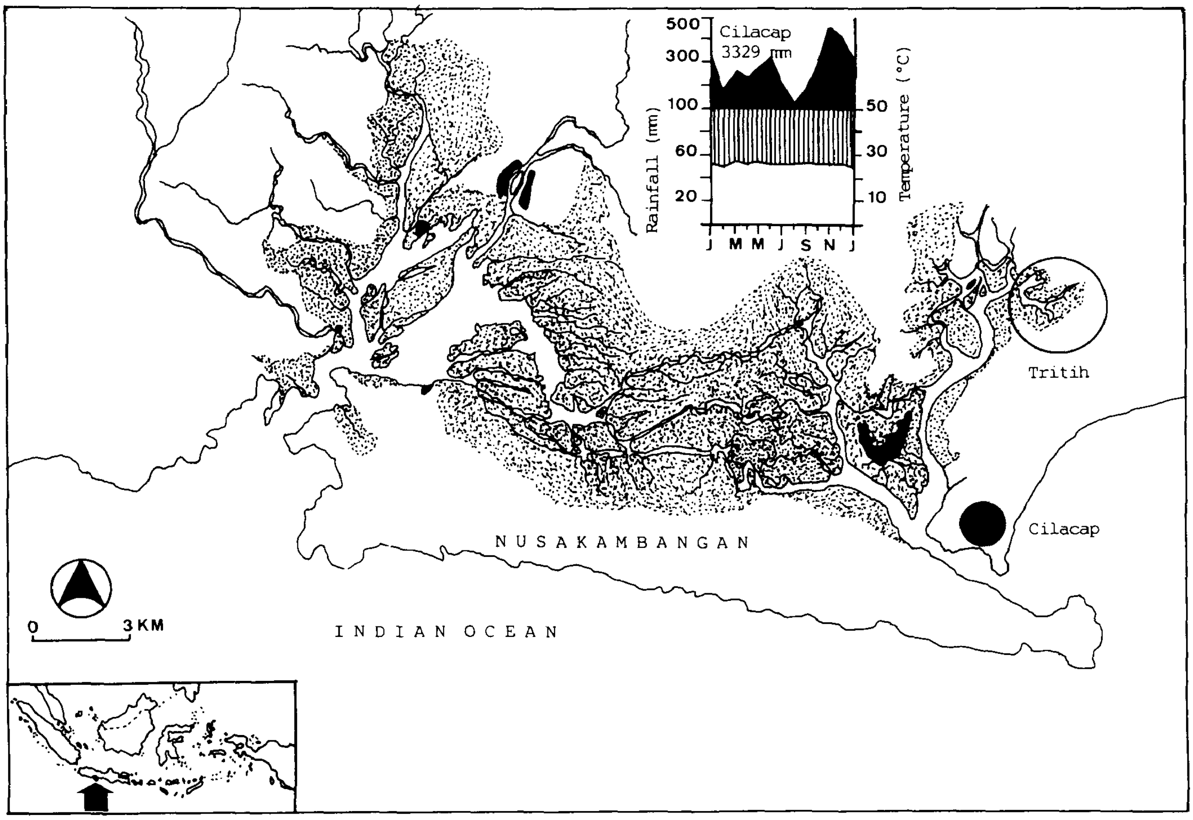

Fig. 1 Location of Tritih Study Area in the Segara Anakan Mangrove Forest, and Climate Diagram for Cilacap

Methods

Weather Data

Standard records of daily maximum and minimum temperature, daily rainfall and wind strength (km 24 h^{-1}) during the study period were obtained from the meteorological station at Cilacap (6 m alt.)

Table 1 Stand Characteristics of *Rhizophora mucronata* Lmk. Plantation in January 1985

Attribute	Site I	II	III	IV	V
Age (years)	7	7	7	7	7
Height range (m)	4.25–6.45	4.25–6.20	4.10–6.10	4.25–6.45	5.70–7.20
MDH* (m)	5.84	5.40	5.20	6.10	7.10
DBH range (cm)	3.55–7.25	3.20–7.16	2.26–6.70	4.30–6.95	3.50–7.95
Basal area (m^2 ha^{-1})	8.296	8.036	5.339	5.421	12.284
Density per ha (stems)	3,250	3,200	3,200	3,300	3,400
Canopy closure (%)	87.75	85.20	80.95	82.25	90.50
Leaf fall (t ha^{-1} $year^{-1}$)	6.907	6.133	5.730	6.036	8.194
Total litterfall (t ha^{-1} $year^{-1}$)	8.193	7.369	7.058	8.236	10.395

*: MDH=Mean Dominant Height=Mean height of the five tallest trees per plot (0.25 ha)

Table 2 Number of Trees according to Diameter Class in the *Rhizophora mucronata* Lmk. Plantation

Diameter Class (cm)	Site I	II	III	IV	V	Total	Basal Area (m^2)
2.00–4.00	651	700	2,400	2,549	200	6,500	8.172
4.01–6.00	2,547	2,460	772	711	1,850	8,340	23.604
6.01–8.00	52	40	28	40	1,350	1,510	7.600
Total	3,250	3,200	3,200	3,300	3,400	16,350	
Basal area (m^2)	8.296	8.036	5.339	5.421	12.284		39.376

and Jumbleng (10 m alt.) some 1 and 5 km from the study site, respectively (Fig. 1). The frequency of days in which temperatures exceeded 24°C, 26.5°C, 29°C, 31.5°C, mean maximum and mean minimum temperatures, total rainfall and mean wind run per collection interval were derived from these records.

Basal Area

The diameter of all living trees greater than 2 cm at 1.3 m height (DBH) or at 30 cm above the highest prop root were measured in January 1985 and the basal area (m^2 ha^{-1}) for *R. mucronata* stands was calculated.

Litterfall

One 0.25 ha plot (50 m×50 m) was established permanently in each study site in the *R. mucronata* Lamarck plantation for the litterfall study in January 1985. Plots were divided into twenty-five 10 m ×10 m subplots. Litter production is usually monitored by collection in litter traps [Newbould 1967]. Thirteen litter traps of 1 m×1 m×0.2 m in size and having a 1 mm nylon mesh base were systematically suspended diagonally by nylon ropes between trees in each 10 m×10 m subplot, at intervals of 10 m and a height of 2 m above the ground, beyond the reach of high tides. The litterfall in each litter trap was sampled at weekly intervals commencing January 1985. Total litter within each trap was sorted into its various components. The litter was then oven-dried at 105°C for 5 days and weighed. The total amounts for each subplot were expressed at t ha^{-1} per collection interval with no correction made for leaching or other losses. Total and leaf litterfall for one year were correlated with weather data.

Results

The total annual litterfall (t ha^{-1}) during the year ranged from 7.058 to 10.395 t ha^{-1} $year^{-1}$ of dry weight in the *R. mucronata* stands. The leaf litter component was dominant in every site, accounting for more than 70% of the total litter (Table 1).

There was a significant linear relationship between the number of live saplings of *R. mucronata* and leaf litter production per subplot site (100 m^2) (both parameters logarithmically transformed). Analysis of variance showed that the number of stems accounted for 85.6% of the variance in litterfall, and there were significant differences in both regression lines per site. Fig. 2 shows a significant linear relationship between basal area of *R. mucronata* Lamarck saplings and the leaf litterfall in each 10 m×10 m subplot (100 m^2), and presents the equation for the regression common to all sites ($Y_{\text{leaf fall}} = -24.374 + 2.361\ X_{\text{basal area}}$, $n=65$, $R^2=0.874$, $p<0.001$).

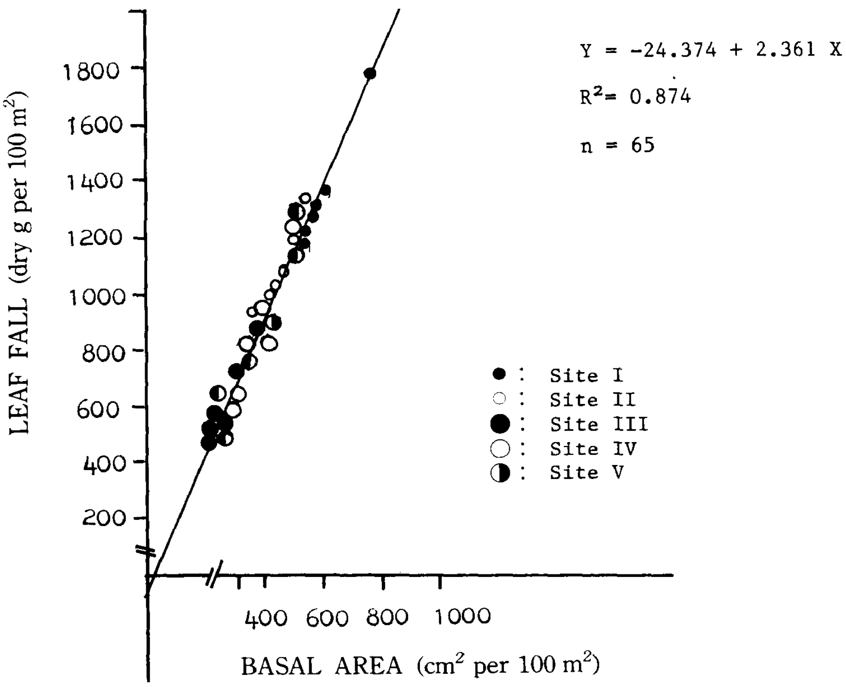

Fig. 2 Basal Area and Leaf Fall for January to December 1985 at Five Sites in the *Rhizophora mucronata* Lmk. Plantation

The correlation matrix relating to environmental variables and litterfall is given in Table 3. Total and leaf litter production were positively related to the temperatures (maximum, minimum, and mean maximum and mean minimum), percent days of typical temperatures, rainfall, and wind run recorded during the sampling interval. There were highly significant differences in the relationship obtained between litterfall and mean maximum temperature for all sites ($p<0.001$) (Table 4). Fig. 3 demonstrates the relationship of the leaf component of litterfall and mean maximum temperature (T) with month/season.

Table 3 Correlation Matrix: Cilacap Meteorological Data and Total Litter and Leaf Litter Production per Sampling Interval

Attribute		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Log total litter	1.	—	0.948	0.913	−0.593	0.736	0.932	0.931	0.862	0.541	0.572	0.898	0.874
Log leaf litter	2.		—	0.951	−0.666	0.796	0.988	0.976	0.988	0.586	0.535	0.852	0.931
Total rainfall	3.			—	−0.673	0.757	0.887	0.958	0.916	0.518	0.514	0.887	0.942
Mean wind run	4.				—	−0.544	−0.540	−0.635	−0.619	−0.519	−0.861	−0.545	−0.710
Max. temperature	5.					—	0.699	0.738	0.653	0.297	−0.112	0.602	0.789
Min. temperature	6.						—	0.981	0.934	−0.189	−0.542	0.870	0.934
Mean max. temp.	7.							—	0.962	0.092	0.404	0.883	0.929
Mean min. temp.	8.								—	−0.043	0.395	0.873	0.853
% day >24°C	9.									—	0.408	0.410	0.416
% day >26.5°C	10.										—	0.890	0.531
% day >29°C	11.											—	0.784
% day >31.5°C	12.												—

Significant level for 1%=0.365; 5%=0.282; m=48

Table 4 Log Mean Maximum Temperature (X) versus Log Total and Leaf Litter Production (Y) per Month in the *Rhizophora mucronata* Lmk. Plantation in Tritih, Cilacap

Plot Number and Litter Category		a*	b*	r^2
Leaf:	I	−7.036	6.429	0.945
	II	−5.308	5.234	0.977
	III	−4.786	4.859	0.919
	IV	−6.093	5.757	0.971
	V	−5.062	5.150	0.964
Total:	I	−7.001	6.456	0.935
	II	−5.764	5.591	0.913
	III	−3.432	4.008	0.830
	IV	−8.210	7.266	0.773
	V	−5.842	5.742	0.804

Notes: * a and b are coefficients for the equation with coefficients of determination, r^2. Log Y=a+b Log X (n=12).

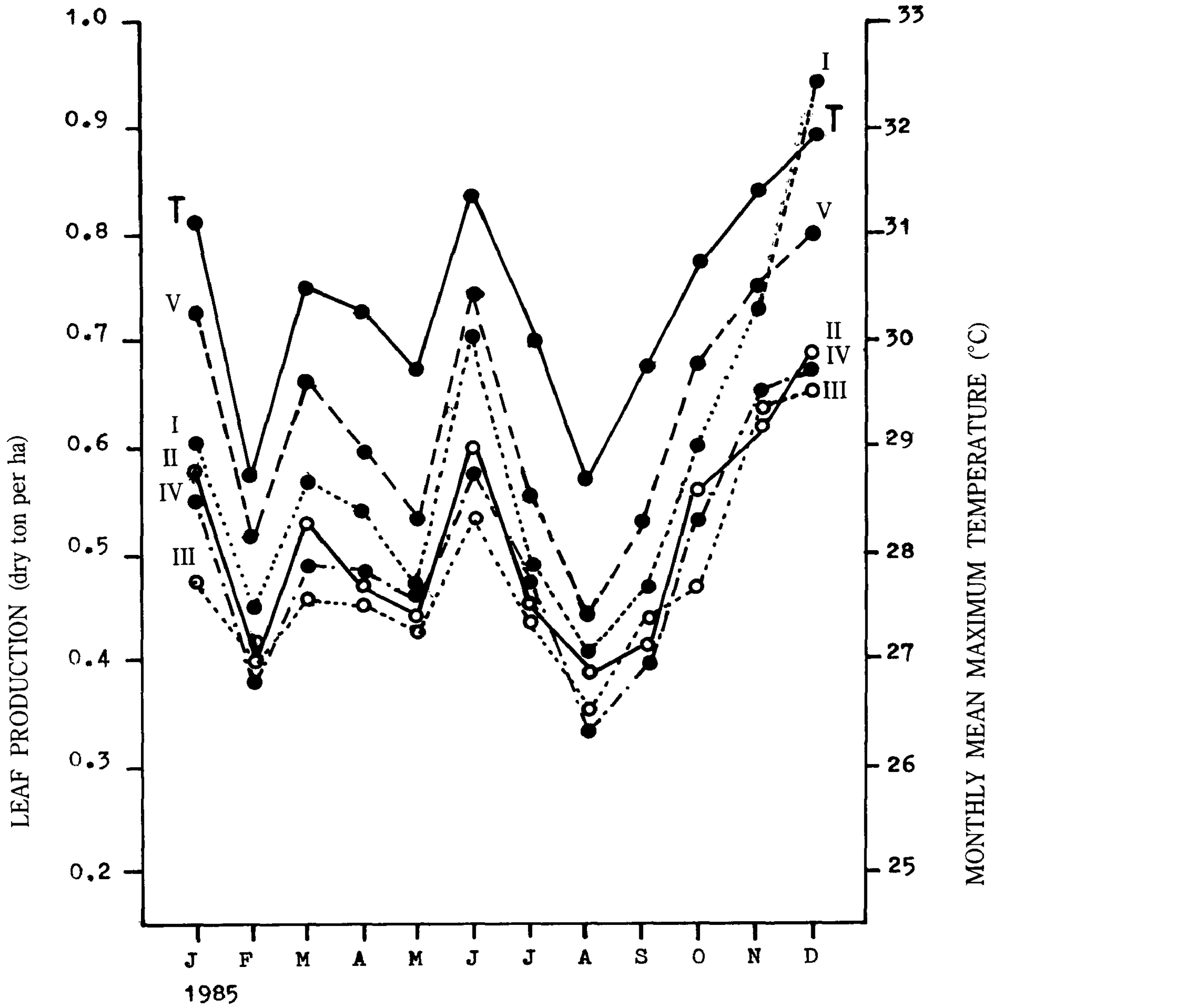

Fig. 3 Leaf Fall per Month during the Study Period (I–V : Sites I–V ; T : Temperature)

The total litterfall at all sites during the one year observation period showed notable peaks in June and December. The December peak, corresponding to the rainy season with more than 300 mm per month, was predominantly composed of leaf litter, which accounted for 76.48% of total litterfall. The incidence of exceptionally high winds may have partially contributed to the litterfall peak ($R^2=0.35$, $n=52$, $p<0.001$). The correlation was improved further with the addition of rainfall ($R^2=0.90$). According to Schmidt and Ferguson's [1951] classification, the Tritih plantation area belongs to climate types A and B, with a Q value of 13 and 25%, respectively. Thus, the plantations are subjected to heavy rain and wind run at this time of year (Fig. 1). The second peak (June, 367 mm) was composed largely of leaf material (87.80% of the total litterfall) and was limited by the reduction of rainfall and field temperatures following the dry season. The production by weight of fallen litter of *R. mucronata* Lamarck during the whole cycle was 79.97% for leaves and 20.03% for the other components. The high proportion of the leaf component was similar to those reported by Sukardjo [1995] for *Rhizophora* forests in Tiris, Indramayu, West Java, and Duke *et al.*

[1981] for several mangrove sites in Missionary Bay, northeastern Australia.

All the parts collected as twigs/branches were small. Fig. 3 also shows the maximum leaf fall during the period of study. There is significant variation in time for every component. A multiple regression analysis showed that the fall of twigs/branches at month t is highly related to the fall of leaves and reproductive materials during the same period ($R^2=0.998$, $p<0.001$).

Discussion

Based on the results presented in Table 3 and Figs. 2 and 3, three points of interest emerge from the statistical study of the relationship of litterfall to basal area and climatic variables:

1. Local total rainfall has much influence on the general conditions of the plantation (i.e., it is statistically independent).
2. Maximum and minimum temperatures, and mean maximum and mean minimum temperatures (see Table 3) and rainfall are highly intercorrelated variables and represent key factors for the general condition of plantation areas.
3. Litterfall is closely associated with both key factors.

In the *R. mucronata* Lamarck plantation, the litterfall is best correlated with basal area as indicated in Fig. 2 and Table 5, and poorly correlated with stand density. Stand density is not a good measure to correlate with litterfall compared with basal area per 100 m^2 for man-made forest, which better reflects the net result of many variables that affect tree growth, including competition within the stand. It may be useful to state basal area of *R. mucronata* stands when presenting estimates of leaf fall. In Tritih, the close correlation between basal area and litterfall of the different sites agrees with general conclusions of Bray and Gorham [1964] for litter production in different world climatic zones. In general, however, litterfall, as Brown [1984] discussed, is caused by senescence or stress, by mechanical factors and by a combination of these. Correlation analysis of environmental variables and litterfall revealed that minimum temperature was the predominant factor affecting seasonality of leaf litter production ($r=0.932$, $p<0.01$) and total litter production ($r=0.932$,

Table 5 Leaf Fall Production (Y) per Month versus Basal Area (X) per 100 m^2 in the *Rhizophora mucronata* Lmk. Plantation in Tritih, Cilacap

Plot Site	b, Slope	a, Intercept	r, Coeff. Correlation	Standard Error for: b, Slope	Standard Error for: a, Intercept
I	1.792	155.663	0.971	0.114	0.095
II	1.776	152.459	0.936	0.113	0.093
III	1.752	−1.454	0.830	0.112	0.001
IV	1.461	23.000	0.904	0.093	0.020
V	2.316	34.828	0.788	0.147	0.021

$Y=a+b\,X$ (n=13)
Y=leaf (dry g)
X=basal area (cm^2)

$p<0.01$) (Table 3). In fact, seasonal variation relates not only to minimum temperature but also to other meteorological factors, for example, wind, air humidity, soil salinity [Twilley *et al.* 1986], and phenology of the plant itself. Rainfall at Cilacap and Jumbleng was at no stage limiting to leaf production ($r=0.913$, $p<0.01$) during the study period. This is also the case in other areas where rainfall remained high throughout the year [Sukardjo 1995]. The high correlation between environmental variation and the shedding of leaves in the *R. mucronata* plantation also suggests that the change in time in the shedding pattern is of adaptive value, as was found for *R. stylosa* Griff. seedlings in the Pari Island [Sukardjo *et al.* 1987]. In Tritih, a strong seasonal variation is found in the lietterfall of different sites with maximum falls occurring during the heavy rain (468 mm per month) in December (Fig. 3). This is in agreement with the generalization of Day *et al.* [1987] that peak litter production usually occurs in the wet season. Moreover, this proved that local rainfall is an important environmental factor in the phenology of *R. mucronata* Lamarck and for other *Rhizophora* species [Christensen and Wium-Andersen 1987; William *et al.* 1981; Sukardjo *et al.* 1987]. Other authors have mentioned general wet and dry periods [Pool *et al.* 1975] and drought conditions [Lugo and Snedaker 1975] as the possible causal factors in the sequence of phenological events in mangrove communities. The significant falls of non-leafy materials may be expected to result from differences in the force of the wind run and heavy rainfall. The variation in temperature (Table 4) and rainfall from month to month will result in variation of both quantity and phenology of leaf fall. It is proved that the frequencies of days in which temperatures exceeded 24°C, 26.5°C, 29°C and 31.5°C play a role in the phenological aspect of *R. mucronata* leaves. Therefore, *R. mucronata* is very sensitive to some temperatures. The demonstrated relationships of leaf litterfall with basal area and maximum and minimum temperatures, and mean maximum and mean minimum temperatures indicate that they are key factors which affect litter dynamics in the *R. mucronata* plantation in Tritih, Cilacap.

It can be concluded generally that wet or dry periods and daily conditions act as possible causal factors in the sequence of phenological events in *R. mucronata* plantation. Although phenological events are relatively synchronous among trees at a particular latitude, and this is consistent from year to year, the phenological status of individual *R. mucronata* Lamarck trees is highly variable between sites and between years. The phenological pattern of *R. mucronata* may simply reflect changes in sediment character in particular site locations of the plantation. Further, within stands, local conditions may act to shift seasonal patterns in litterfall in time to some extent and perhaps also in quantity. The responses of the *R. mucronata* plantation are possibly associated with the characteristic geomorphic environment of the plantation: mainly basins in the upper intertidal zone and mudflats in the Tritih study area and other areas of Segara Anakan (see Fig. 1). This affects the canopy height pattern of individual *R. mucronata* trees, and consequently contributes significantly to litter production and basal area of *R. mucronata* plantation.

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